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Cover Photograph:
Sungai Rait (SR) outcrop (Pliocene Tukau Formation, Cycle VI)

By: Franz L. Kessler and John Jong

Berita Sedimentologi

• Published 3 times a year by the Indonesian Sedimentologists Forum (Forum Sedimentologiwan Indonesia, FOSI), a commission of the Indonesian Association of Geologists (Ikatan Ahli Geologi Indonesia, IAGI).
• Cover topics related to sedimentary geology, includes their depositional processes, deformation, minerals, basin fill, etc.
Dear Readers,

Berita Sedimentologi No. 43 was initially planned for publication in March/April, however we were not able to fill up the required minimum number of manuscripts due to various reasons. I’m glad that now we are able to publish two high quality articles in this volume.

This issue contains research articles on sandstone diagenesis observed on outcrop examples in Miri, northern Sarawak and on the stratigraphic distribution of Neogene dinoflagellate cysts which were sampled from Kebabangan-1 well in offshore Sabah, north Borneo. I believe that both articles would be useful to our readers, especially in SE Asia Region.

We had some changes within FOSI organization recently, where Ricky Tampubolon was chosen to be the new General Secretary of FOSI. Ricky is a petroleum geologist working for Odira Energy Karang Agung and he was previously a researcher at Lemigas Jakarta. His research interests include carbonate stratigraphy, biostratigraphy and sedimentology. Ricky now also serves as one of the Deputy Chief Editors of Berita Sedimentologi.

I would like to invite you to write for Berita Sedimentologi. The next issue (Berita Sedimentologi No. 44) will be published in September this year. As I mentioned earlier, we have had some difficulties to get high quality manuscripts to be considered for inclusion in our journal. Berita Sedimentologi accepts manuscripts on various topics related to sedimentology, sedimentary geology and petroleum geology. We hope that you are willing to share your work through our publication. Do contact one of our editors if you’re interested to publish in Berita Sedimentologi. Your contribution certainly will be highly appreciated.

Best regards,

Minarwan
Chief Editor

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BERITA SEDIMENTOLOGI

Berita Sedimentologi #44 call for paper to: iagifosi@gmail.com
About FOSI

The forum was founded in 1995 as the Indonesian Sedimentologists Forum (FOSI). This organization is a communication and discussion forum for geologists, especially for those dealing with sedimentology and sedimentary geology in Indonesia.

The forum was accepted as the sedimentological commission of the Indonesian Association of Geologists (IAGI) in 1996. About 300 members were registered in 1999, including industrial and academic fellows, as well as students.

FOSI has close international relations with the Society of Sedimentary Geology (SEPM) and the International Association of Sedimentologists (IAS). Fellowship is open to those holding a recognized degree in geology or a cognate subject and non-graduates who have at least two years relevant experience.

FOSI has organized three international conferences in 1999, 2001 and the most recently in 2018.

Most of FOSI administrative work will be handled by the editorial team. IAGI office in Jakarta will help if necessary.

The official website of FOSI is: http://www.iagi.or.id/fosi/

FOSI Membership

Any person who has a background in geoscience and/or is engaged in the practising or teaching of geoscience or its related business may apply for general membership. As the organization has just been restarted, we use LinkedIn (www.linkedin.com) as the main data base platform. We realize that it is not the ideal solution, and we may look for other alternative in the near future. Having said that, for the current situation, LinkedIn is fit for purpose. International members and students are welcome to join the organization.

FOSI Group Member as of June 2019: 987 members
DESTRUCTIVE DIAGENESIS OBSERVED IN OUTCROP EXAMPLES OF NEOGENE SANDSTONE RESERVOIR AND CLAY CONTACT ZONES, MIRI, NORTHERN SARAWAK

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ABSTRACT

The occurrence of diagenetic siderite and iron oxide deposits has been recognized in offshore subsurface reservoirs of Baram Delta fields. Iron-rich intra-reservoir deposits are relatively common in coastal Sarawak, but good examples are rare. In this article, we present outcrop examples of the Miri area. In three selected locations, geometries and composition of diagenetically-derived iron precipitates can be explored, measured and analyzed. The destructive impact of siderite rims on net reservoir volume for STOIIP calculation, and their potential interaction with chemicals used for enhanced oil recovery (EOR) is also noted.

Keywords: diagenesis, siderite, reservoir, Neogene, sandstone, clay

INTRODUCTION

The occurrence of diagenetic siderite rims within Neogene sandstone reservoirs was recognized and probed by A.R. Abdul Hadi & T.R. Astin (1995) in cores of the Baram Field in offshore Sarawak. Authigenic siderite was found to form cemented zones in sandstone reservoirs bordering clay-dominated sequences, with a maximum thickness of 200 cm. The effect of the diagenesis led to deposition of siderite and caused a marked reduction of reservoir quality to 10 % porosity and 2 mD permeability, hence producing a very marginal reservoir for both oil and gas. The understanding of siderite deposition in sedimentary sequences is important mainly in the context of two investigative subjects:

(i) Volumetric calculations. It is important to discount siderite rims, and these may not be counted as net reservoir;
(ii) The strong presence of iron-rich deposits may interact with enhanced oil recovery agents affecting chemical EOR performance (e.g., Lee et al., 2018).

In April 2019, the authors led a short field campaign in the surroundings of Miri, northern Sarawak, with the objective to investigate siderite rims, and to locate suitable outcrops, where siderite deposits can be studied.

REGIONAL GEOLOGY AND STRATIGRAPHIC SETTING OF MIRI AREA

The greater Miri area is characterized by moderately folded siliciclastics of Neogene age: the Late Miocene Miri and Lambir formations, and the Pliocene Tukau Formation, as illustrated in Figure 1. The Lambir and Tukau formations form the subject of this article, which was investigated during our recent field excursion.

A simplified litho-stratigraphy scheme of the investigated area is shown in Figure 2 (Jong and Kessler, 2017):

• The Pliocene Tukau Formation unconformably overlies the Lambir/Miri formations and was formed by intertidal clastics, in particular tidal channel deposits, which appear strongly amalgamated, and are interbedded with silty parallel layers. Individual channel beds are often characterized by “side-stepping” and asymptotic foresets, in which laminae can consist of thin, gray claystone or of lignite (Kessler and Jong, 2015 & 2016).

• The Mid-Late Miocene Lambir and Miri formations form the crestal area of the Bukit Lambir and Miri Hills (Figure 1). These formations contain about equal amounts of claystone and sandstone, the latter mainly formed by (sometimes nested) tidal channels and beach bars. Most channels are “reworked” and strongly amalgamated (Kessler and Jong, 2015 & 2016).
DIAGENETIC PROCESSES LEADING TO SIDERITE DEPOSITS

Reservoir diagenesis observed in offshore Malaysian fields varies. In offshore Peninsular Malaysia (Malay and Penyu basins), we see in particular mobility of SiO₂ and recrystallisation (Ibrahim and Madon 1990; Tan 2009; Maga et al., 2015; Kessler and Jong, 2018). Along the NW Borneo margin however, such as the Baram Delta, diagenetic effects are less severe and are mainly characterized by dolomite and siderite cements (A.R. Abdul Hadi and T.R. Astin, 1995).

The Baram Delta basin offshore Miri is formed by sandstone and clay deposits, and very minor carbonate occurrences. Sandstone dominates the shallow (Miocene to Pleistocene) stratigraphy, whilst clay is abundant within the older (Oligocene to Mid Miocene) record (Kessler and Jong, 2015). In simplified terms, the following physical and chemical processes take place:

When clay compacts, it releases cation-rich fluids, again once the clay minerals recrystallize; they eject additional fluids (Figure 3). Iron is also released when pyrite within the clay matrix is oxidized leading to Fe²⁺ ions, these being mobilized as Fe₂S₀₄. Clay-derived and relatively acidic fluids percolate in the sedimentary deposits, pervade sandstone reservoirs and interact with the original, relatively alkaline reservoir fluids.

These contain Ca⁺⁺ and Mg⁺⁺ ions in the form of calcium and magnesium carbonate (CaHCO₃, CaMgCO₃). The reaction leads to a precipitation of siderite (FeCO₃) and dolomite (MgCa(CO₃)₂), leading to rim deposits at the sandstone/claystone interface.

In the studied outcomes, we observe siderite (mostly transformed to hematite) lacing sandstone to clay boundaries. In the outcrops, the iron deposits reach a maximum thickness of some 10 cm, forming an observed migration barrier for fluid mobility and reducing permeability. Interestingly, the layers are of laterally constant thickness suggesting that the observed sediments are derived from regional rather than punctual processes.

OUTCROPS FOR SIDERITE STUDIES

Although “iron rims” are pervasive and are seen on many sandstone-to-claystone boundaries, we would like to single out three outcrops, which are relatively easy to access and allow studies on the 100 m to 1 mm scales. A location map of studied outcrops is shown in Figure 4.

Sungai Rait (SR) Outcrop (approximate coordinates: 4.2655°N/113.9539°E)

The youngest Cycle VI sediments (Tukau Formation) of the Miri area are deposited in the –
Figure 2: Simplified litho-stratigraphy scheme of northern Sarawak with approximate equivalent offshore Cycle interval shown. The term Miri Formation is generally used in the greater Miri area and is age-equivalent to the upper section of the Lambir Formation, Sandal (1996) however, placed the formation partially age-equivalent to the lower Tukau Formation. Likewise, the mid Early Miocene Sibuti Formation is more locally confined with the Subis Limestone Member deposited in the lower part of the Gray Upper Setap Shale (Banda and Honza, 1997). Carbonates are also widespread in the Palaeogene section, and are seen in a number of outcrops and wells (e.g., Batu Niah, Engkabang-1; Jong et al., 2016). The observed unconformity events as annotated are established by Kessler and Jong (2017), and modified after Kessler and Jong (2015).
Figure 3: Schematic illustration of fluid expulsion events in the Setap Shale, Miocene, Baram Delta, Sarawak (after Morley et al., 2014). Cation-rich fluids are expelled from clay, as the latter is being heated up during burial.
Liku Sycline, and were penetrated by two freshwater wells during the 1990’s, but there are no significant outcrops. The Sungai Rait outcrop is located in the shallowest outcropping stratum of the Cycle VI Tukau Formation, the outcrop shows a cliff formed by massive clay, which hosts several sandy channel complexes (Figures 5 and 6). The composite clay and channel sequence is capped by a sandy layer formed by amalgamated channelized sandstone beds. Overall, we observe braided intertidal-shallow marine sands in lenses and ribbons, in which (mainly) sandy channel fills incise a thin-bedded intertidal-deltaic sequence. The sequence corresponds to a gross reservoir unit with laterally strongly varying poro-perm and flow barriers.

**Figure 4:** Approximate locations of the studied outcrops shown as red stars in context of a regional tectonic map, and see text for location coordinates (SR = Sungai Rait Outcrop. LL = Long Lama Road Outcrop near Kampung Liku, some 10 km from Beluru in the inset map. CR = Coastal Road Outcrop some 5 km from the Tusan Junction). The orange Baram Line constitutes an important facies boundary, with carbonate dominate in Luconia/Tinjar and clastics in the Baram Delta Block.
**Figure 5:** Sungai Rait (SR) outcrop (Pliocene Tukau Formation, Cycle VI).

**Figure 6:** Sungai Rait (SR) outcrop. Dr. Jong pointing to a 7 cm thick veneer of massive iron-rich sediment (oxidized siderite, probably hematite).
Long Lama Road (LL) Outcrop near Kampung Liku (coordinates: 3.8756°N/114.0880°E)

At the flank of the Miri to Long Lama road near Beluru, along the road from Miri to Long Lama, there is a profile of the Late Miocene Lambir Formation (Figures 7 and 8; Kessler and Jong, 2015), shown by a series of clay to sandstone interfaces where we can observe:

- Slumped coastal sediments within slope deposits;
- Diagenesis affecting sandstone beds at the Base Cycle V unconformity, as well as on several sandstone / claystone contacts within the Cycle V sequence (Figures 8 and 9).
- Angular Base Cycle VI unconformity. During our last visit, the precise location of the unconformity was overgrown. There is a marked change in dip between the marine beds of Cycle V, and flat-lying Cycle VI deposits formed by coal and non-marine sand. Unfortunately, the beautiful outcrop of 2012 is now almost entirely overgrown by creeper plants (Figure 10). Therefore, it may not be possible to carry out comprehensive studies, without clearing the underbrush cover, and a sample was subsequently retrieved for further analysis (Figure 11).

**Figure 7:** The fresh Long Lama Road (LL) Kampung Liku outcrop in 2012 (Kessler and Jong, 2015). The contact zones between sandy and clay packages display a pink-brown colour.

**Figure 8:** Detail of the fresh outcrop in 2012, hematite band at the base of pink sandstone (right hand sequence in Figure 7).
Figure 9: Long Lama Road (LL) Miocene Lambir Formation, Cycle V. Red-brown veneers of hematite are seen lining the boundary between a porous sandstone and prominent clay bed. It corresponds to the upper pink sandstone shown in Figure 7.

Figure 10: The overgrown Long Lama Road (LL) outcrop in 2019, photo taken during the recent fieldtrip.
Figure 11: A sample from Figure 9 outcrop area was retrieved for further analysis, with a five cents coin for scale.

Coastal Road (CR) near Tusan Junction (coordinates: 4.1215°N/113.8500°E, ca. 33 m above sea level)

About 2 km from the Tusan Junction along the Coastal Road, this outcrop is located in the lower section of the Pliocene Tukau Formation, with beds that are steeply dipping (Figure 12). The unconformity contact to the underlying Lambir Formation is not exposed, and likely overprinted by a series of strike-slip faults running roughly parallel to the Coastal Road.

The sequence exposed in the outcrop consists of alternating intertidal (often bioturbated) sandstone and clay laminae. Fossils, other than massive crab burrows have not been preserved. In this particular outcrop we see iron oxides (derived from siderite) staining sand laminae individually (Figure 11), but a thicker hematite deposit is seen at the sand-to-claystone interface. In subsurface reservoirs, these iron oxide layer would have formed a permeability barrier for fluid mobility in addition to occluding the pore spaces.

Figure 12: Coastal Road outcrop (CR) Pliocene Tukau Formation, Cycle VI. Iron oxides have impregnated well-sorted and layered sandstone. Inset figure shows the details of iron oxide layering in porous sandstone.
CONCLUSIONS

The Miri area offers a number of good outcrops, in which geometries and composition of diagenetically-derived iron precipitates can be explored, measured and analyzed. In subsurface reservoirs, these iron oxide deposits occurring in porous layers would form a significant barrier for fluid mobility and also reduce the effective net reservoir volume for STOIIP calculation. In addition, the strong presence of iron-rich deposits may interact with enhanced oil recovery agents thus affecting chemical EOR performance.

REFERENCES


THE STRATIGRAPHIC DISTRIBUTION OF NEOGENE DINOFLAGELLATE CYSTS FROM A DEEP WATER WELL, OFFSHORE SABAH, NORTHERN BORNEO

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ABSTRACT

A research project was initiated with the objective to establish a dinoflagellate cyst biozonation for deep water wells drilled offshore Sabah and Brunei, Northern Borneo, to complement the biozonations based on nannoplankton, foraminifera and spores-pollen.

Analysis of dinoflagellate cysts in ditch cutting samples from deep water well Kebabangan-1, offshore Sabah, resulted in a list of FDO’s, which could be of stratigraphic value: Hystrichokolpoma rigaudiae at 3150’, Operculodinium sp. A at 3840’, Dapsilidinium pastielsii at 4140’ and Lingulodinium pycnospinosum at 4950’ within the Pliocene section; Selenopemphix brevispinosa subsp. conspicua at 5760’ and consistent occurrence of Achomosphaera sp. B at 5760’ within the Upper Miocene section. Samples from appraisal well Kebabangan-2 were examined for calibration.

Dinoflagellate cysts have been recovered from mud-rich shelfal topsets and underlying mud-rich slope fan systems in the interval 2610’ to 6495’, while the basal sand-rich base-of-slope fans in the interval 6705’ to 7805’ were barren of palynomorphs. A dinoflagellate biozonation is not yet proposed based on analyses of one well and cursory examination of the appraisal well. The correlation potential of the FDO’s reported for this well needs to be confirmed in follow-up wells along the Northern Borneo offshore.

INTRODUCTION

The objective of this study was to establish a dinoflagellate cyst biozonation for deep water wells drilled offshore Sabah and Brunei, Northern Borneo, to complement the routinely used biozonations based on nannoplankton, foraminifera and spores-pollen.

The first phase of this project, palynological analyses of a pilot well, was carried out in 2001-2002, while the author was employed by Curtin University in Perth, Australia, as senior lecturer at the then existing Centre of Excellence in Petroleum Geology. Results were presented at the 34th Annual Meeting of the American Association of Stratigraphic Palynologists in San Antonio, USA (Van den Brink 2002, abstract only), and an abbreviated version was published in Berita Sedimentologi 16 (2001).

Because of the limited amount of publications on dinoflagellate cysts of Neogene age in low latitudes and specifically in SE Asia (e.g. Van Gorsel, 2014), it seems useful to fully document the stratigraphic distribution of dinoflagellate cysts from a deep water well drilled offshore Sabah.

Dinoflagellate cysts are the prime markers in the Mesozoic biozonations of wells drilled in the Australian Margin, including the deep offshore. The main justification to initiate the research project was the expectation that dinoflagellate cysts could play an equally important role in the marine Neogene sediments in SE Asia. For this purpose, the deep water well Kebabangan-1, offshore Sabah, was selected, for palynological analysis, complemented with a scan of samples from appraisal well Kebabangan-2, drilled in the same structure (Figure 1).

A substantial number of deep water wells were drilled offshore Sabah and Brunei. Its objective sequences are Miocene-Pliocene turbiditic reservoirs, deposited in a prodeltaic deep water (bathyal) environment. Major gas and minor oil resources have been identified, i.e. in the Kebabangan Field (Figure 1).

Biostratigraphy plays an important role in the deep water drilling campaign, since correlations based on seismic are hampered by heavy faulting. Calcareous nannoplankton presently provides a high resolution Neogene biozonation for the deep water wells, with foraminifera and pollen as
additional support for age dating. Dinoflagellate cysts are expected to represent an alternative biostratigraphic ‘tool’ in case nannoplankton markers are absent in future wells, since both microfossil groups are supposed to occur in sediments deposited in the deep water environment, encountered in the deep water wells.

In order to be useful in wells for which only ditch cutting samples are available, the envisaged new dinoflagellate cyst biozonation should mainly be based on F(irst) D(ownhole) O(ccurrence)'s of key dinoflagellate cysts. Acmes of dinoflagellate cysts could be of correlative value at local scale. ‘

REGIONAL SETTING OF KEBABANGAN-1 WELL

The modern subaerial and submarine morphology of West Sabah is assumed to be an analogue to the Miocene-Pliocene turbidite play (Figure 1). The exceptionally large height differential of about 7–

km, over only 200 km between the mountainous hinterland, (coastal Crocker Ranges and the Mt. Kinabalu plutonic complex; 4101 m) and the base of the continental slope (about 3000 m water depth) is very different from other ‘classical’ turbidite provinces (e.g. Gulf of Mexico). The submarine morphology comprises a 80-100 km wide shelf, passing into a steep continental slope (2-10°). The sediments were transported from the hinterland into the offshore by multiple rivers, and the succession indicates an overall regressive trend since Late Miocene times.

The studied pilot well Kebabangan-1 is located 80 kilometers offshore and penetrated high energy, sand-rich, base of continental slope fans at the objective interval. These are covered by low energy, mud-rich continental slope fan systems, grading upward into mud-rich shelfal topsets at shallow depth.

**Figure 1:** Location map of Kebabangan gas field (Asia Pacific Oil & Gas News, adapted)
The Kebabangan-1 well was drilled in 1994 to test the deepwater turbidites in a structural closure created by shale diapirism along a major fault (Figure 2). It was the first discovery drilled in the SB-1 PSC, at a location 12km NE of Kinarut-1 (1972). The bounding fault of the structure has a significant strike-slip component with a very steep thrust fault. The well drilled to a total depth of about 11,300' and penetrated 4000' of turbidite sands (Chua, 1998).

Dinoflagellate cysts have been recovered from the mud-rich shelfal topsets and underlying mud-rich slope fan systems; the underlying sand-rich base-of-slope fans (Figure 2) were barren.

**Figure 2**: Seismic Line across Kebabangan-1 (Challis et al, 2015).
PREVIOUS DINOFLAGELLATE STUDIES IN THE AREA

A limited amount of studies on dinoflagellate cysts of Tertiary age in low latitudes and specifically in SE Asia has been published. Dinoflagellate cysts from the Eocene Nanggulan Formation and the Miocene Sentolo Formation in Central Java were discussed by Matsuoka (1981, 1983a, 1984). Taxa reported from the Sentolo Formation, of relevance to present study, include *Operculodinium* sp. and *Spiniferites* sp.

Besems (1993) listed the dinoflagellate cysts of Tertiary age from Northern Borneo, as compiled and described by Shell palynologists in the last 30 years. Dinoflagellate cysts were recovered from specific thin intervals in about 40 wells, supposedly representing marine incursions in coastal environments. None of these walls penetrated sediments deposited in bathyal/slope environments over the full section, in contrast to the present deep water well. Besems (1993) proposed a range chart of selected dinoflagellate cysts of Tertiary age for Northern Borneo, based on these scattered dinoflagellate cyst occurrences, calibrated with the other palynomorphs, in the above wells. Most of his selected dinoflagellate taxa are long ranging and therefore he proposed a biozonation based on successive dinoflagellate cyst assemblage groups. This biozonation is of little use to the current study, since variations of the three successive dinoflagellate cyst assemblages covering the Neogene interval are not reflected in the palynological analyses of Kebabangan-1. Furthermore, Protoperidiniacean dinoflagellate cysts were not included in his review, since most of these were removed by Shell’s sample processing technique that included oxidation. Therefore an important part of the dinoflagellate cyst microflora was not recorded.

Of further relevance to the present study are the Neogene dinoflagellate cysts reviews by McMinn (1992 and 1993), as part of the Ocean Drilling Program, from the Eastern Indian Ocean and the Northeastern Australian Margin, because of the relative proximity in (sub)tropical environment. Sediments from the first location were initially deposited on the outer continental shelf and slope and have been redeposited at their present location on the Argo Abyssal Plain by density currents. Sediments from the second location were deposited at outer neritic to bathyal water depths on submerged margin plateaus off the northern Queensland coast.

PALYNOCLOGICAL ANALYSES OF KEBABANGAN-1

Thirty three ditch cutting samples from well Kebabangan-1 were provided by Sarawak Shell Berhad and prepared by Laola Pty Ltd in Perth. Palynological analyses of dinoflagellate cysts only have been carried out.

Dinoflagellate cysts are restricted to the interval from 2610’ to 6495’ (Figure 3). A set of slides prepared from the oxidized fraction of the samples was fully analyzed, with counts of dinoflagellate cysts. In addition, the un-oxidized fractions were screened for thin walled Protoperidiniacean dinoflagellate cysts, like *Selenopemphix* spp., *Brigantedinium* spp. and *Lejeunecysta* spp., the bulk of which had been removed by oxidation. Protoperidiniacean dinoflagellate cysts are illustrated in Plate 3. The palynological assemblages are overwhelmingly dominated by land plant material, i.e. pollen, spores, fungi and macerals. Marine elements (dinoflagellate cysts, acritarchs and algae) overall contribute just 2 to 5 % of the microflora in the interval from 2610’ to 6495’. From 6705’ to 7905’ the ditch cutting samples are virtually barren of marine palynomorphs. They still contain some (caved?) pollen and spores, but are dominated by dark brown debris.

**Biostratigraphy**

The interval from 2610’ to 4020’ has been assigned to the Upper Pliocene, the interval from 4140’ to 5430’ to the Lower Pliocene and the interval from 5640’ to 6495’ to the Upper Miocene, based on the distribution of calcareous nanoplankton with support from foraminifera and pollen, as reported by the operator.

The dinoflagellate cyst assemblages are dominated by (cf.) *Brigantedinium* spp., *Spiniferites* spp. and *Operculodinium* spp. The adjective cf. applies to *Brigantedinium* spp. without a clearly visible archeopyle. The *Spiniferites* spp. have been subdivided into three morphogroups: (1); *Spiniferites ramosus* group, (2) group with *Spiniferites hyperacantha* and *Spiniferites mirabilis* and (3) group with smaller forms including *Spiniferites bulloideus*. Most of the *Operculodinium* spp. can be allocated to *Operculodinium centrocarpum* sensu Wall 1967. Large size varieties of *Operculodinium israelianum* and *Operculodinium wallii* (Matsuoka 1983) are common, similar to those described in the tropical
Neogene environment in the Bahamas (Head and Westphal, 1999). Impagidinium spp. (incl. I. paradoxum, I. aculeatum and I. patulum), Selenopemphix nephroides, Selenopemphix quanta, Tuberculodinium vacancopae, Polysphaeridium zoharyi and Lingulodinium machaerophorum are consistently present over the full interval.

A suite of FDO’s (and acmes) of dinoflagellate cysts in descending order is presented over the study interval. The FDO’s of dinoflagellate cysts marker species are referred to the published stratigraphic ranges. However, since these mainly originate from North American and European dinoflagellate cysts reviews at higher latitudes, their applicability in low-latitude SE Asia has yet to be established.

**Interval 2610’- 4020’: Upper Pliocene**

The FDO of Hystrichokolpoma riguadiae at 3150’ could be of stratigraphic value. However, highest occurrences have been reported within the Pleistocene in the Western and Northern Pacific (Bujak and Matsuoka 1986), the Gulf of Mexico (Wrenn and Kokinos 1986) and the Mediterranean (Londeix et al. 1999).

A very distinctive FDO in this interval belongs to the informal species Operculodinium sp. A., a large size (80-90 microns) proximochorate dinoflagellate cyst with a precingular archeopyle, densely covered with fibrous processes. It has been allocated to Operculodinium spp., as advised by Head and Norris independently (pers. comm. 2001). It could be of considerable stratigraphic importance with a consistent range from 3840’ downwards.

**Interval 4140’- 5430’: Lower Pliocene**

The FDO of Dapsilidinium pastielsii at 4140’ is considered to coincide with the top of the Lower Pliocene interval, as established by calcareous nannoplankton. Also Besems (1993) reported a FDO of Dapsilidinium pastielsii at the top of the Early Pliocene for NW Borneo. Its highest occurrence has been reported in the Late Pliocene in the Eastern Indian Ocean and the Northeastern Australian Margin (McMinn 1992, 1993).

Also the FDO of Lingulodinium pycnostominosum at 4950’ is considered to be of stratigraphic value. The highest occurrence to date was reported in the Late Oligocene in Germany (Benedek and Sarjeant 1981).

Several rare occurrences have been detected in this interval which could have stratigraphic potential; Homotrebylum tenuispinosum with FDO at 4290’ (reworked?), Lejeunecysta cf. sp. 2 (Biffi and Grignani 1983) with FDO at 4950’, Spiniferites sp. A (Duffield and Stein 1986) with FDO at 4950’ and Trinovantidinium ferugnomatum at 5115’. Lejeunecysta cf. sp. 2, nearest resembling Lejeunecysta cf. sp. 2, has been recorded in the Oligocene sediments of the Niger Delta (Biffi and Grignani 1983). Spiniferites sp. A has been detected in sediments of Middle to Late Miocene age in the Gulf of Mexico, but the analyzed interval did not extend into the Pliocene (Duffield and Stein 1986). The highest occurrence of Trinovantidinium ferugnomatum has been reported from the Late Pliocene in the eastern United States (De Verteuil and Norris 1992).

The acritarch species Comaspheeria spp., present over the full analyzed section, shows an acme at 5115’. From 5430’ to 6270’ (Upper Miocene) Spiniferites spp. and Brigantidinium spp. are relatively rich. Both events could be of local stratigraphic value.

Analysis of ditch cutting samples invalidates the use of LDO’s. However, it should be noted that (in ditch cutting samples) thin walled dinoflagellate cyst species Bassardinium cf. graminosum and Bassardinium evangelinae (Head 1993; Lentin et al. 1994) and Achomosphaera granulata are restricted to the Pliocene interval. The published occurrence of Bassardinium evangelinae ranges from Late Miocene to Pleistocene in eastern Canada (Williams et al. 1998). The irregularly shaped Bassardinium cf. graminosum shows similarities to the Miocene species Bassardinium graminosum. Achomosphaera granulata with very distinct granular surface has been reported from the Quaternary in the South China Sea (Mao and Harland 1993).

**Interval 5640’- 6495’: Upper Miocene**

The Late Miocene age assignment by calcareous nannoplankton and foraminifera is supported by the FDO at 5760’, and consistent presence underneath this depth, of Selenopemphix brevispinosa Head et al. 1989 subsp. conspicua, which has a published highest occurrence in the Late Miocene in the eastern United States (De Verteuil and Norris 1992, 1996). The scattered occurrences in the Pliocene interval have been interpreted as reworking, although it should be mentioned that it locally occurs in Pliocene sediments in the Mediterranean as well (Londeix et al 1999).

A further support for the Miocene age assignment for this interval could be provided by the top of -
### Ditch Cutting Samples

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- **Barssidinium cf. graminosum**
- **Barssidinium evangelineae**
- **Achomosphaera granulata**
- **Achomosphaera sp. A**
- **Operculodinium sp. A**
- **Dapsilidinium pastielsii**
- **Homotryblium tenuispinosum**
- **Lingulodinium pycnospinosum**
- **Achomosphaera sp. B**
- **Lejeunecysta cf. sp. 2 (Biffi & Grignani, 1983)**
- **Xandarodinium xanthum**
- **Spiniferites sp. A (Duffield & Stein, 1986)**
- **Lejeunecysta spp.**
- **Trinovantidinium ferugnomaticum**
- **Quadris? Condita**
- **Selenopemphix dionaeacysta**
- **Selenopemphix brevispinosa subsp. conspicua**
- **Lejeunecysta cinctoria**
- **Edwardsiella sexispinosum**
- **Cordosphaeridium sp. A**
- **Surculosphaeridium sp. (Duffield & Stein, 1986)**
- **Systematophora placacantha**

**Figure 3:** Kebabangan-1 Dinoflagellate cyst distribution chart
the consistent occurrence of informal species *Achomosphaera* sp. B at 5760’, occasionally also present in the Lower Pliocene interval of the well. It has a thick-walled spherical shaped central body and is covered by thin processes. These distinctive features point into the direction of an undescribed species, although allocation to an *Achomosphaera* spp. morphogroup cannot be excluded.

Over the Upper Miocene interval in the well several single occurrences of diagnostic dinoflagellate cysts have been recorded to be discussed next. It should be realized that their stratigraphic value could be doubtful (reworking, contamination?).

An established marker species for the top of the Late Miocene is *Systematophora placacantha*. Its highest occurrence has been reported in the Late Miocene in Italy (Powell 1986). A single presence has been recorded at 6495’.

Of stratigraphic importance in this interval could also be the single presence of *Quadrina? condita* at 5640’, *Lejeunecysta cinctoria* at 5760’ and *Surculosphaeridium* sp. (Duffield and Stein 1986) at 6435’. *Quadrina? condita* (= Gen. et sp. indet. A of Duffield and Stein 1986) has been reported from the Middle to Late Miocene in the eastern United States (De Verteuil and Norris 1992, 1996). The youngest occurrence of *Lejeunecysta cinctoria* has been recorded from the Oligocene sediments of the Niger Delta (Biffi and Grignani 1983). *Surculosphaeridium* sp. has been reported from the Early to Middle Miocene in the Gulf of Mexico (Duffield and Stein 1986).

The single presence of *Selenopemphix dionaeacysta* at 5640’, *Edwardsiella sexipsinosum* at 5995’ and informal species *Cordosphaeridium* sp. A at 6270’ could also be of significance. However, the highest occurrence of *Selenopemphix dionaeacysta* has been reported in the Late Pliocene in the eastern United States (De Verteuil and Norris 1992) and *Edwardsiella sexipsinosum* in the Late Pliocene in Italy (Versteegh and Zevenboom 1995). *Cordosphaeridium* sp. A shows similarities to *Operculodinium* sp. A. The fibrous processes are longer and less densely distributed.

**PALYNOLOGICAL ANALYSES OF KEBABANGAN-2**

Palynological analyses of twenty five ditch cutting samples (interval 4132’to 7000’) from nearby well Kebabangan-2 (2001) were carried out in order to calibrate the results of Kebabangan-1. Dinoflagellate cysts are restricted to the interval from 4245’to 6165’. The organic content of the slides and resulting palynomorph density is about four times lower than in Kebabangan-1, resulting in Kebabangan-2 dinoflagellate cyst assemblages to be a diluted copy of Kebabangan-1.

The interval from 4245’ to 4485’ has been assigned to the Upper Pliocene, the interval from 4605’ to 5325’ to the Lower Pliocene and the interval from 5445’ to 6165’ to the Upper Miocene, based on correlation with Kebabangan-1, supported by the distribution of nannoplankton in both wells.

FDO’s in the top section of Kebabangan-1, like *Hystrichokolpoma rigaudiae* and *Operculodinium sp.* A, are not recognized in Kebabangan-2, since the top of the interval of investigation is deeper in the section (4245’vs. 2610’). The top of the Lower Pliocene interval in Kebabangan-2 at 4605’ is based on the FDO of *Dapsilidinium pastieslai* in correlation with Kebabangan-1, followed by the single occurrence of *Lingulodinium pygenosphorum* at 4725’. The top of the Upper Miocene interval in Kebabangan-2 at 5445’ is based on correlation with Kebabangan-1. It is supported by the top consistent occurrence of *Selenopemphix brevispinosa* subsp. *conspicua* in the next downhole samples in both wells. Overall, the diluted dinoflagellate cyst microfloras of Kebabangan-2 confirm the stratigraphic events established in Kebabangan-1.

**ENVIRONMENTS OF DEPOSITION**

From regional geological studies and seismic data it has been established that the environment of deposition penetrated in the interval from 2610’ to 6495’ in Kebabangan-1 ranges from outer shelfal (outer neritic) at the top (mud-rich shelfal topsets), to lower continental slope (lower bathyal) at the base of the section (low energy mud-rich continental slope fan system). Below 6495’ the Kebabangan-1 well penetrated high energy, sand-rich, base of the continental slope fans (the objective interval).

In a deep marine environment of deposition (outer shelf to lower continental slope), rich dinoflagellate cyst microfloras are expected, with dinoflagellate percentages of 50% or more of total palynomorphs (including landplant pollen, spores, fungi and macerals) and a species diversity of 25 or higher, analogous to the scheme applied to the Mesozoic sediments of the Australian margin. It is obvious that this scheme is not applicable to the Neogene sediments in Kebabangan-1. In the interval from 2610’to 6495’ the dinoflagellate cyst...
content ranges from 2 to 5% of total palynomorphs, and diversity is between 10 and 20 species. The low percentage of dinoflagellate cysts and moderate species diversity is explained by severe dilution by land plant material, discharged by major rivers, and transported across the continental shelf into the low energy, mud-rich outer shelf and slope fan systems at a distance of 100–150 km from the coastline.

The dinoflagellate cysts assemblages, encountered in Kebabangan-1 between 2610’ and 6495’, are dominated by *Brigantedinium* spp., *Spiniferites* spp. and *Operculodinium* spp., while *Polysphaeridium* zoharyi, *Selenopemphix nephroides*, *Tuberculodinium vancampae* and *Lingulodinium machaerophorum* are commonly present. These assemblages are supposed to be characteristic for tropical inner to outer neritic shelfal environments (Harland 1983; Wrenn and Kokinos 1986; Brinkhuis 1992a; in: Jansonius and McGregor 1996). Genera indicative of oceanic environments like *Impagidinium* spp. and *Nematospaeropsis* spp. are rare. The dinoflagellate cyst assemblages show similarities to the Neogene (sub)terrestrial assemblages from the Eastern Indian Ocean and the NE Australian Margin (McMinn 1992, 1993). However, assemblages of the ODP wells show a higher species diversity with e.g. *Impagidinium* spp., *Batiacasphaera* spp. and *Melitasphaeridium choanophorum* commonly present as well.

From regional geological studies and seismic data it is clear, that the dinoflagellate cysts assemblages encountered in Kebabangan-1 in the interval 2610’ to 6495’, are not derived from inner to outer neritic shelfal environments, but from a more distal zone (outer neritic/shelfal to upper bathyal/slope environment). This zone is characterised by upwelling of oceanic waters, rich in nutrients, responsible for high oceanic productivity. Upwelling of deep, cold ocean currents is common, especially at low latitudes. From this zone, only short distance transport of dinoflagellate cysts into the mud-rich slope fan sediments occurred.

The influx of fresh water from multiple river mouths onto the shelf probably causes dinoflagellate assemblages to predominantly occur in outer neritic to upper bathyal environments, as reduced salinities have an adverse impact on the inner shelfal dinoflagellate microfloras. High discharge of fresh water is indicated by the long distance offshore transport of land plant material across the shelf. The lower species diversity of dinoflagellate cysts in the Borneo deep water well compared to the ODP wells in the Eastern Indian Ocean and the NE Australian Margin, also deposited in outer shelf to slope environments (McMinn 1992, 1993), could also be due to influx of less saline water (slightly higher numbers of *Impagidinium* spp. in the ODP wells could indicate stronger oceanic influence).

The decrease in numbers of *Brigantedinium* spp. and *Spiniferites* spp. going upwards in the section in the interval from 2610’ to 6495’ in Kebabangan-1 could be due to shallowing of the environment of deposition, moving away from the zone of nutrient-rich upwelling. This confirms the overall regressive trend from the Late Miocene to present day.

The interval from 6705’ to 7905’ in the deep water well represents the top of the high energy, sand-rich, base-of-slope fan reservoir section of the well. The sands lack palynomorphs.

**CONCLUSIONS AND RECOMMENDATIONS**

This research project with the objective to establish a dinoflagellate cyst biozonation for deep water wells drilled offshore Sabah and Brunei was envisaged to complement the biozonations based on nannoplankton, foraminifera and pollen. The palynological analysis of deep water well Kebabangan-1, offshore Sabah, was complemented with a quick analysis of well Kebabangan-2, drilled in the same structure.

Low percentages of dinoflagellate cysts relative to landplant material and moderate species diversities were encountered in Kebabangan-1. However, dinoflagellate cyst recovery is sufficient to produce a stratigraphic useful distribution. A list of FDO’s is presented, which could contain stratigraphic value: *Hystrichokolpoma rigaudiae* at 3150’, *Operculodinium* sp. A at 3840’, *Dapsilidinium pastielsii* at 4140’ and *Lingulodinium pycnospinosum* at 4950’ within the Pliocene section; *Selenopemphix brevispinosa* subsp. *conspicua* at 5760’, and consistent occurrence of *Achomosphaera* sp. B at 5760’ within the Upper Miocene section.

Dinoflagellate cysts were recovered from mud-rich shelfal tops and underlying mud-rich slope fan systems from 2610’ to 6495’. The underlying sand-rich base-of-slope fans in the interval 6705’ to 7905’ were barren of palynomorphs.

A dinoflagellate cyst biozonation cannot yet be proposed based on results of one well, complemented with a scan of the appraisal well. The correlation potential of the FDO’s reported for this well needs to be confirmed in additional wells,
both along the Northern Borneo offshore and from other parts of SE Asia.

There is still the potential for dinoflagellate cysts to become a powerful tool in Neogene biostratigraphy of SE Asia, as they are in the Paleogene of the North Sea and in the Mesozoic of the Australian margins. However, additional analytical studies are needed, preferably in conjunction with a re-evaluation of palynological processing techniques. Dinoflagellate cysts are generally less robust and more delicate than the associated spores and pollen and many of them may not be preserved in standard palynology slides. Un-oxidized slides should be prepared for the determination of the thin walled Protoperidiniacean dinoflagellate cysts, which are removed by the standard preparation.

ACKNOWLEDGEMENTS

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REFERENCES


Londeix, L. et al. 1999. Late Neogene dinoflagellate cyst assemblages from the Strait of Sicily, Central Mediterranean Sea: paleoecological


PLATE 1 – Gonyaulacales Dinoflagellate Cysts

All figures X 600, KBB-1 unless otherwise indicated

1. Acho(mosphaera granulata) Mao Shaozhi, 1989
   2610’: Upper Pliocene
2, 3. Acho(mosphaera sp. B
   5955’ and 6270’: Upper Miocene
4. Spiniferites hyperacanthus (Deflandre and Cookson, 1955) Cookson and Eisenack, 1974
   5640’: Upper Miocene
5, 6. Dapsilidinium pastielisii (Davey and Williams, 1966) Bujak et al., 1980
   5640’ (2x): Upper Miocene
7. Hystrichokolpoma rigaudiae Deflandre and Cookson, 1955
   5640’: Upper Miocene
   4740’: Lower Pliocene
   5640’: Upper Miocene
   2970’: Upper Pliocene

PLATE 2 – Gonyaulacales Dinoflagellate Cysts

   Large size specimen (see text).
   3150’:
2. Operculodinium wallii (Matsuoka, 1983)
   Large size specimen. Some authors allocate it to O. centrocarpum s. l.
   4290’: Lower Pliocene
3, 4. Operculodinium sp. A
   4140’ and 4290’: Upper and Lower Pliocene
   2850’: Upper Pliocene
   4290’: Lower Pliocene

PLATE 3 – Protoperidiniacean Dinoflagellate Cysts

1, 2. Selenopemphix nephroides Benedek, 1972
   4290’: Lower Pliocene, KBB-2, 4845’: Lower Pliocene
3, 4. Selenopemphix brevispinosa subsp. conspicua de Verteuil and Norris, 1992
   3450’: Upper Pliocene, KBB-2, 4365’: Upper Pliocene
   4290’: Lower Pliocene, KBB-2, 5565’: Upper Miocene
7. Leneuncycsta sp.
   KBB-2, 4845’: Low Pliocene
8. Lejeunecysta cf. sp. 2 (Biffi and Grignani, 1983)
   4950’: Lower Pliocene
   5760’: Upper Miocene
10. Lejeunecysta sp. ‘small’
    KBB-2, 5565’: Upper Miocene
11. Brigantedinium simplex Wall 1965
    6270’: Upper Miocene
12. Quadrina ‘condita’ de Verteuil and Norris, 1992
    5640’: Upper Miocene
    2850’: Lower Pliocene
14. Barssidinium evangelineae Lentin et al. 1994
    4020’: Upper Pliocene
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SECTION 2: INFORMATION ABOUT PRICES, SIZES & DEADLINES

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- BS#40 ----- 11 Mar 2018
- BS#41 ----- 11 Jun 2018
- BS#42 ----- 11 Sep 2018

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